AE-451A: Experiments in Aerospace Engineering-III

Experiment # 2

a): Measure velocity profile, both mean and fluctuating component in the turbulent wake behind a circular cylinder using hot wire-anemometer

b):Study the dependence of shedding frequency in the Karman vortex street of the circular cylinder wake on Reynolds number

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Objective:

- Measure velocity profile, both mean and fluctuating component in the turbulent wake behind a circular cylinder using hot wire-anemometer
- Study the dependence of shedding frequency in the Karman vortex street of the circular cylinder wake on Reynolds number

Introduction and Theory:

External flows past objects have been studied extensively because of their many practical applications. For example, airfoils are made into streamline shapes in order to increase the lifts, and at the same time, reducing the aerodynamic drags exerted on the wings. On the other hand, flow past a blunt body, such as a circular cylinder, usually experiences boundary layer separation and very strong flow oscillations in the wake region behind the body. In certain Reynolds number range, a periodic flow motion will develop in the wake as a result of boundary layer vortices being shed alternatively from either side of the cylinder. This regular pattern of vortices in the wake is called a Karman vortex street. It creates an oscillating flow at a discrete frequency that is correlated to the Reynolds number of the flow. The periodic nature of the vortex shedding phenomenon can sometimes lead to unwanted structural vibrations, especially when the shedding frequency matches one of the resonant frequencies of the structure.

Flow Separation: The presence of the fluid viscosity slows down the fluid particles very close to the solid surface and forms a thin slow-moving fluid layer called a boundary layer. The flow velocity is zero at the surface to satisfy the no-slip boundary condition. Inside the boundary layer, flow momentum is quite low since it experiences a strong viscous flow resistance. Therefore, the boundary layer flow is sensitive to the external pressure gradient (as the form of a pressure force acting upon fluid particles). If the pressure decreases in the direction of the flow, the pressure gradient is said to be favorable. In this case, the pressure force can assist the fluid movement and there is no flow retardation. However, if the pressure is increasing in the direction of the flow, an adverse pressure gradient condition as so it is called exist. In addition to the presence of a strong viscous force, the fluid particles now have to move against the increasing pressure force. Therefore, the fluid particles could be stopped or reversed, causing the neighboring particles to move away from the surface. This phenomenon is called the boundary layer separation.

Vortex Shedding: The boundary layer separates from the surface forms a free shear layer and is highly unstable. This shear layer will eventually roll into a discrete vortex and detach from the surface (a phenomenon called vortex shedding). Another type of flow instability emerges as the shear layer vortices shed from both the top and bottom surfaces interact with one another. They shed alternatively from the cylinder and generates a regular vortex pattern (the Karman vortex street) in the wake. The vortex shedding occurs at a discrete frequency and is a function of the Reynolds number. The dimensionless frequency of the vortex shedding, the shedding Strouhal number, St = fD/V, is approximately equal to 0.21 when the Reynolds number is greater than 1,000.

Vortex-Induced Vibrations: When vortices shed from the cylinder, uneven pressure distribution develops between the upper and lower surfaces of the cylinder, generating an oscillatory aerodynamic loading (lift) on the cylinder. This unsteady force can induce significant vibrations on a structure, especially if the "resonance" condition is met. The most famous example is the collapse of Tacoma Narrow bridge in 1940 under the action of wind-induced vibrations. It is believed that natural vortex shedding frequency behind the bridge matches one of the resonant modes of the bridge and eventually lead to a catastrophic vibration that destroys the bridge.

Momentum Balance: As stated earlier, the external force acting on an object can be determined using the momentum balance concept. In general, there is a momentum deficit in the wake profile along the streamwise direction as relative to the incoming momentum upstream of the object. Therefore, a simple balance of the momentum flow in and out of the control volume surrounding the object suggests that there is net force acting on the object. (note: the pressure is considered to be relatively constant if the momentum flow is measured far away from the object.) This net force along the flow direction is called the drag. Averaged velocity profiles of the flow past a circular cylinder is provided as a general representation of the wake flow field. Selected profiles at several representative regions is also presented for your reference. Near the cylinder, flow separates from the surface. Immediately behind the cylinder, a recirculation region exists with a strong reversing flow. The region between the cylinder and the end of the recirculation region is called the vortex formation region. The centerline velocity becomes zero at the end of the vortex formation region. Further downstream, the two separating shear layers merge and the velocity profile presents a typical wake profile. It is clear that there is a deficit in the center of the wake. This deficit in the momentum flow is the direct result of drag force acting on the cylinder.

Constant temperature hot wire anemometer: The hot wire anemometer is used to measure flow velocity. Flow cools down the hot wire & carries away some heat resulting in a reduction of temperature. Due to reduction in temperature, resistance of the wire changes. So, we have to supply some additional voltage to maintain a constant temperature. That voltage can be correlated to flow velocity.

Experimental Setup:

Figure 1 showing hot wire anemometer positioning

Equipment:

- Low speed wind tunnel
- Cylinder
- Hot-wire Anemometer
- Pitot tube
- Digital differential manometer
- NI data acquisition card.
- Computer

Procedure:

A)

- Study the experimental set-up including each and every component with specification.
- Study the circuit diagram for a constant temperature hot wire circuit.
- Mount the hot-wire probe in the traversing mechanism and make the necessary signal connection.
- Make a block diagram of the experimental set up.
- Calibrate hot wire probe in the free stream without any model in the tunnel.

- Use a rough cylinder model to generate turbulent wake
- At one free stream wind speed at a stream-wise station, x, measure velocity profiles, both mean and fluctuating component, in the turbulent wake. The origin of x coordinate is at the center of the cylinder and it is increasing in the streamwise direction.
- Plot velocity profiles, both mean and rms, in normalized forms.

B)

- You are provided with four circular cylinders of different diameters. Measure the diameters with the help of a digital Vernier.
- Mount the hot wire in the near wake (about 3 diameters) of the circular cylinder. Turn the wind tunnel on. At an appropriate wind speed the hot wire signal will show a sine wave. Note the frequency of the sine wave. This corresponds to the frequency of the vortex shedding.
- Increase the Reynolds number and note the variation in the shedding frequency.
- Calculate Strouhal number, $S=fd/V$ and Reynolds number. Plot results as $S=f(\mathrm{Re})$.

Measurement and Calculation:

Part A

Cylinder diameter used=9.5 mm

Part A

Cylinder diameter used=1.2mm

Results and observation:-

Part A)

Calibration

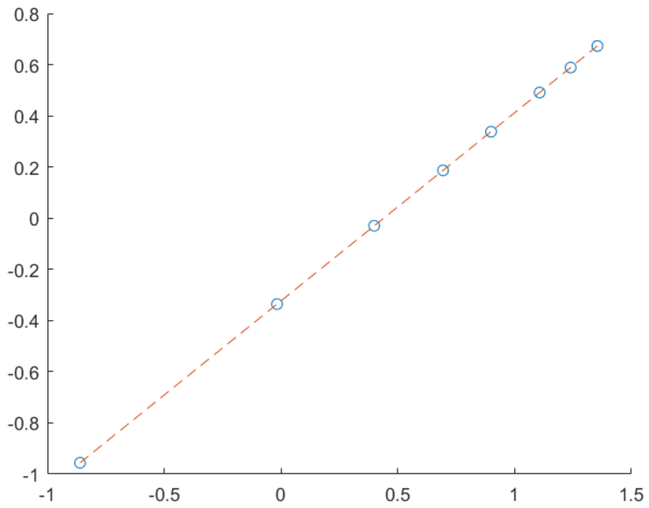


Fig 2 showing $\log(E^2 - Eo^2)$ vs $\log(U)$

A=2.9687 B=0.7239 n=0.7355

Wake region

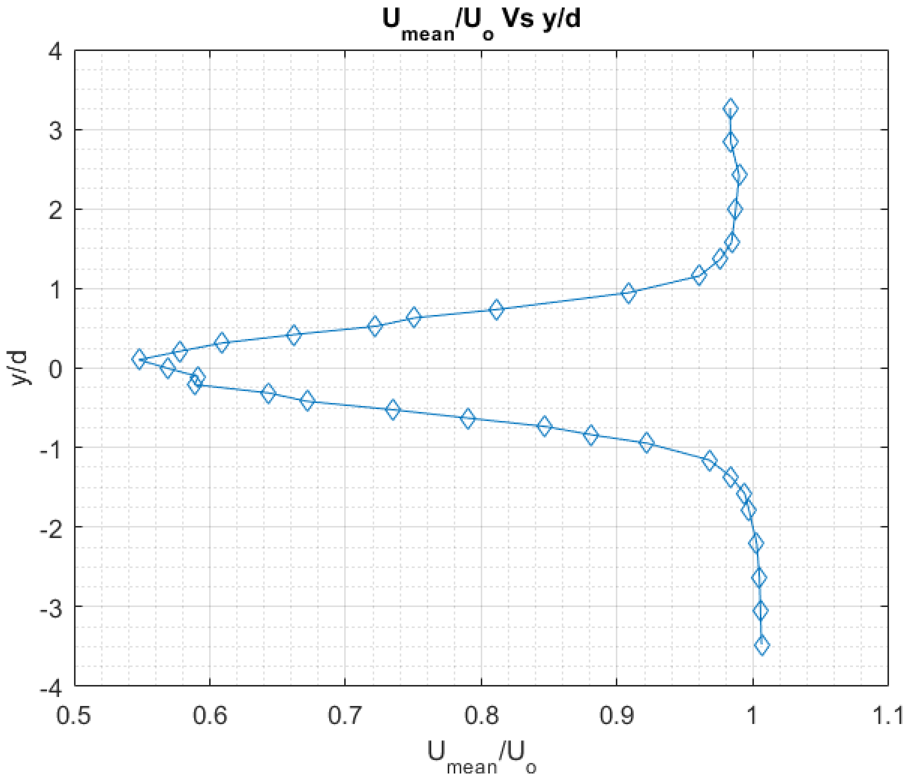


Fig. 3 showing non-dimensioned mean velocity variation with y

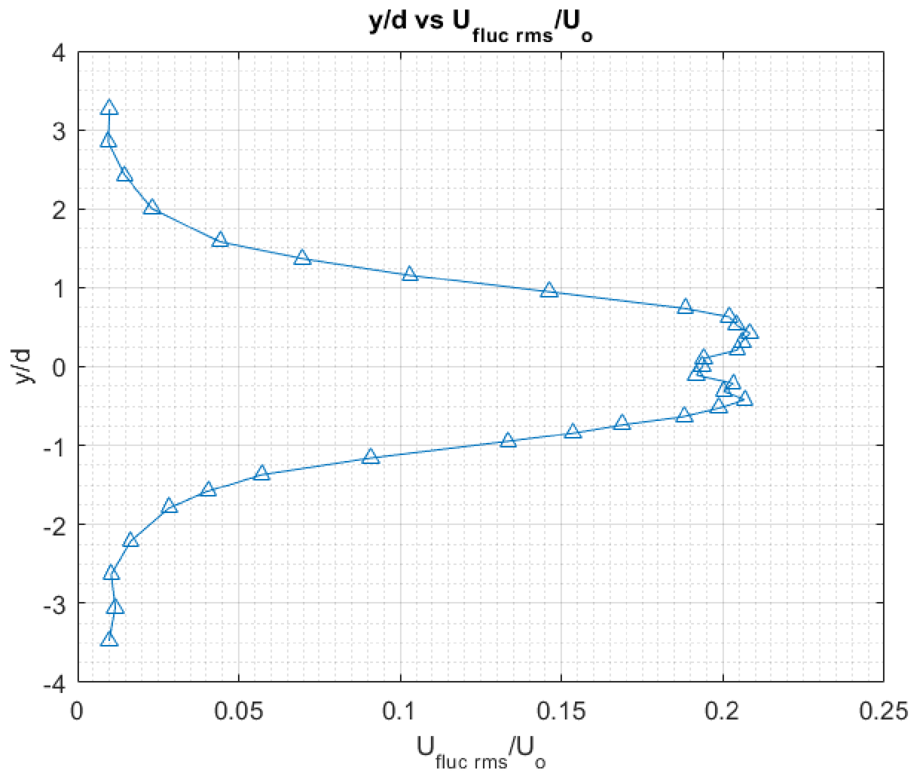


Fig 4 showing non-dimensioned fluctuating rms velocity variation with y

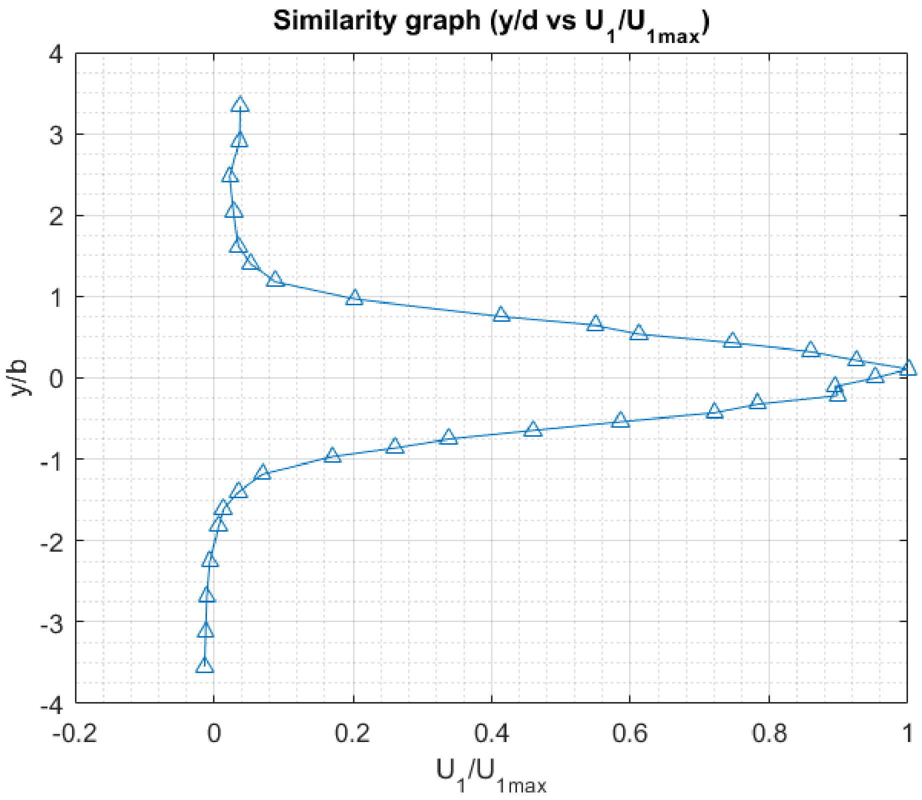
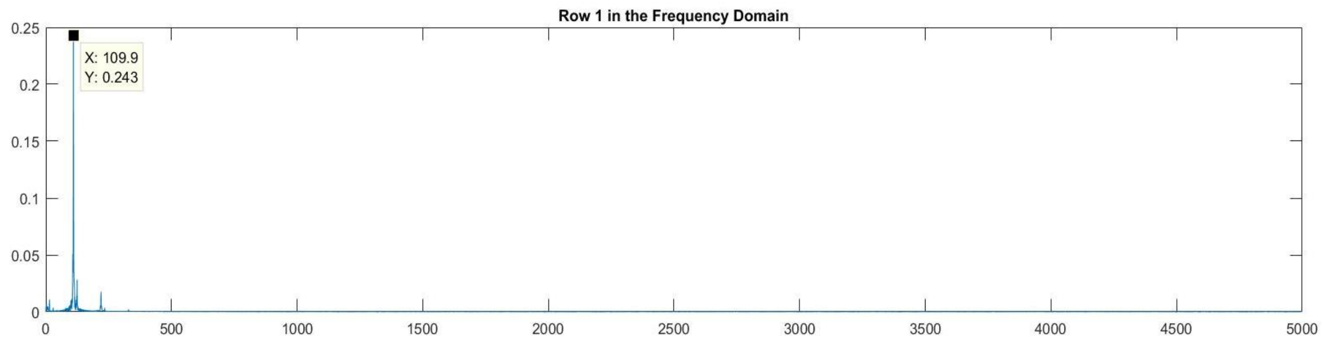


Fig 5 non-dimensioned showing similarity graph

Part B)

FFT



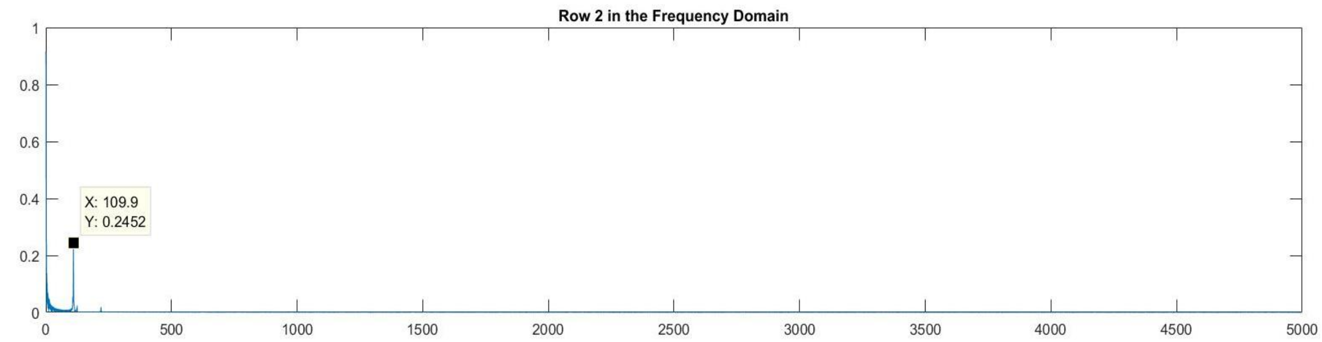


Fig 6 showing fft of velocity (Row1=1m/s, Row2=1m/s)

Strouhal number=fd/v=109.9*1.2/1000=1.3188

Part A) Questions-

1)How does constant temperature hot-wire anemometer work?

------- The hot wire anemometer measures the fluid velocity by measuring the heat convicted away by the fluid flowing past it. The total heat transfer depends on the flow velocity (which is to be measured), the physical properties of the fluid, the difference in temperature between the fluid and the wire and the dimensions and the physical properties of the wire. First the anemometer is calibrated using King's law and then we use the coefficients to get velocity data.

2) How do you calculate mean and rms velocity components from hot wire signal?

-------- Mean velocity is the average of the velocity data obtained after converting voltage data from hot wire anemometer into velocities using King's law. To calculate rms velocity first we have to compute the fluctuating part of the velocities. Fluctuating component can be obtained by subtracting U by Umean. The square root of squared average of the fluctuating components of velocity gives the rms velocity.

3) What is the nature of the hot-wire signal in the free stream?

-------- In free stream since there is no disturbances present in front of the flow. The fluctuating components of the velocity will be negligible and the velocity will remain constant at a point.

4) What do you understand by the intermittency in a turbulent wake?

-------- Intermittency is the flow regime which lies in between laminar and turbulent region or it can be defined as a scale to measure the transfer of flow from laminar to turbulent. For a fully laminar flow the value of intermittency is 0, while for turbulent it is 1.

Part A) Questions-

1)What do you observe when the hot wire probe is moved across the cylinder wake?
Explain the reason.

------We see there is more loss of momentum in wake region close to cylinder vertically.

2) Can you use this method to measure low wind speed? Explain.

------- Yes, we can use this for measuring low velocity because hot wire anemometer is very sensitive to rate of heat loss since its resistance changes.

4) What happens to the shedding frequency when the hot wire probe is moved across the cylinder near wake? Explain.

--------When a probe is moved across the cylinder wake then we observe some fluctuations in the signal. As it is moved further downwards in the wake the fluctuations will decrease and then it will again increase as it now shows fluctuations in downward part

Data calibration constant:

U	E
0	1.723
0.423	1.824
0.983	1.931
1.49	1.998
2	2.053
2.457	2.095
3.025	2.141
3.454	2.172
3.873	2.199